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2. The Effect of Interference on Delta Modulation

Encoded Video Signals

Annual Report

October 1, 1978 - October 1, 1979

NASA Johnson Space Center

Houston, Texas

under

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DEPARTMENT OF ELECTRICAL ENGINEERING



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THE CITY COLLEGE OF
THE CITY UNIVERSITY of NEW YORK



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1.0 Introduction

This final report summarizes the activities conducted under NASA CONTRACT NAS 9-13940 during the time period October 1, 1978 to September 30, 1979.

During this period we designed, constructed, and delivered to NASA/JSC an adaptive delta modulator which encode composite color video signals. The ADM was shown to provide a good response when operating at 16 Mb/s and near-commercial quality at 23Mb/s. In addition, the ADM was relatively immune to channel errors.

The system design is discussed here and circuit diagrams are included.

2.0 A Real Time Delta Modulator with Error Correction

Of the three error correction algorithms investigated the leaky integrator error correction technique gave the best results and is also the easiest to implement.

We designed a real time delta modulator using a leaky integrator for error correction. A block diagram is shown in Fig. 2.1. The leak factor α was chosen to be .968. If the estimate before the leak is called X_k and if the estimate after the leak is $X_k^{(l)}$ then the equation defining the leaky integrator is given by:

$$X_k^{(l)} = .968X_k + 2$$

$$X_k^{(l)} = X_k - \frac{X_k}{32} + 2 \quad (2.1)$$

Since X_k assumes values between zero and 127, the addition of the value of 2 to Equation 2.1 causes X_k to leak symmetrically about the midvalue 63. As an example consider that when X_k equals zero, $X_k^{(l)}$ will leak up to the value +2; when X_k equals 127, $X_k^{(l)}$ will leak down 2, to the value +125; and when X_k assumes the midvalue 63, $X_k^{(l)}$ will remain unchanged. The addition of the number 2 minimizes the distortion caused by leaking X_k while having no effect on the leaking away of errors.

The implementation of the leaky integrator is shown in Fig. 2.2. The subtraction of $X_k/32$ from X_k is carried out in Fig. 2.2 by shifting X_k five places and subtracting it from X_k . The addition of +2 in Equation 2.1 is carried out by the same subtractor by using the inverted value of the most significant bit of X_k as the six most significant bits of $X_k/32$. Also notice that the 6 least significant bits leak before the storage register and the 4 most significant bits leak after the storage register. In order to split up the leaky integrator

this way it is necessary to store the carry out (C_{out}) from the subtractor that leaks the 6 least significant bits so that it will appear at the carry in (of the subtractor that leaks the 4 most significant bits) at the same time that the estimate appears at the subtractor's inputs.

The leaky integrator was split up this way (half the leak on X_{k+1} and half on X_k) to minimize the effect of the carry propagation delay through the subtractor on the sampling rate of the delta modulator. Before any storage register's can be clocked, the C_{out} signal must be present and (see Fig. 2.2) the comparator's output must have settled down. With only 6 bits to propagate through, the C_{out} signal will appear before the comparator's output settles down therefore, the subtractor to the left of the storage register is not part of the maximum delay time path of the delta modulator and will not affect the sampling rate of the delta modulator. If the subtractor to the right of the storage register (in Fig. 2.2) is to be part of the maximum delay time path, the propagation delay of the subtractor would have to be greater than that of the step size generator. This is not the case; hence, the leaky integrator split up as in Fig. 2.2 will not affect the sampling rate of the delta modulator. If the leaky integrator was placed entirely to the left or right of the storage register then the carry propagation delay would be sufficient to reduce the maximum sampling rate of the delta modulator.

Because the leaky integrator has only 10 bits, and not 12, the effects of a channel error may not leak away completely. Under worst case conditions the estimate at the delta modulator decoder could remain 3 quantization levels greater than, or less than, the estimate at the encoder. To remove the last vestige of channel errors the estimate at the encoder and decoder are both forced to their minimum value of zero at the end of each scanning line. Also, the step size is forced to its maximum value of 15 and E_{k-1} is forced to -1 in both the encoder and decoder at the end of each scanning line. This ensures that the encoder and decoder begin each scanning line in the same state, free of any remaining channel errors.

The conditions described above are forced upon the delta modulator in a very simple fashion. The negative going sync pulse on the composite video

signal from the TV camera is set to a voltage more negative than the most negative output of the D/A converter of Fig. 2.1. When the sync pulse occurs the estimate is driven to the zero quantization level and held there by the saturation logic. Since the sync pulse is more negative than the zero quantization level the comparator of Fig. 2.1 outputs $-E_k$ during the sync time. The string of $-E_k$'s are fed back to the step size generator and causes the step size to grow to its maximum value.

The complete circuit diagrams for the delta modulator encoder and decoder are shown in Figs. 2.3, 2.4, 2.5 and 2.6. Figure 2.3 shows the input signal from the TV camera being band limited to 4 MHz, DC restored, buffered, and then clamped to 1 volt peak-to-peak. The output of Fig. 2.3 is fed into the input of Fig. 2.4. Figure 2.4 is the complete circuit schematic of the delta modulator encoder with error correction. Figure 2.5 is the circuit schematic of the delta modulator decoder. Figure 2.6 is the detailed schematic of the analog output of the decoder. It shows the circuitry which restores the sync pulses to the composite video signal. The delta modulator was built out of ECL 10,000 series logic and it has a maximum clock rate of 23 MHz.

A series of tests were made with the delta modulator. The first test was to see the effects of the delta modulation of the 4 MHz composite video signal at clock rates of 6, 8, 16 and 23 MHz. The resulting pictures were of good quality at 16 MHz and almost of broadcast quality of 23 MHz. For the second test we introduced errors at 10^{-4} , 10^{-3} and 10^{-2} errors per bit. The pictures of Fig. 2.7 show the effects of errors. At 10^{-4} errors per bit the errors are almost unnoticeable. At 10^{-3} the errors are noticeable but not annoying. At 10^{-2} errors per bit the picture information is still intelligible but the errors are very annoying.

3.0 Conclusions

The delta modulator described here fulfills the objective of this study. The delta modulator can digitize a video signal while providing nearly error free pictures with bit error rates as high as 10^{-4} errors per bit. The delta modulator is also cost effective. It consists of only 21 IC's and consumes only 12 watts of power. Its only shortcoming lies in the fact that its bandwidth compression is only 2:1 for undistorted encoding of TV pictures.

The delta modulator was constructed and delivered to NASA/JSC in 1979.

4.0 Papers Published

1. "Digital Encoding of NTSC Color Video Signals Using Adaptive Delta Modulators", S. Davidovici, D. L. Schilling, K. Land, ICC Convention Record, 6/80, pp. 31.1.1-31.1.5.

5.0 PhD Students Supported

This contract supported the research of Dr. Norman Scheinberg and Mr. Sorin Davidovici.

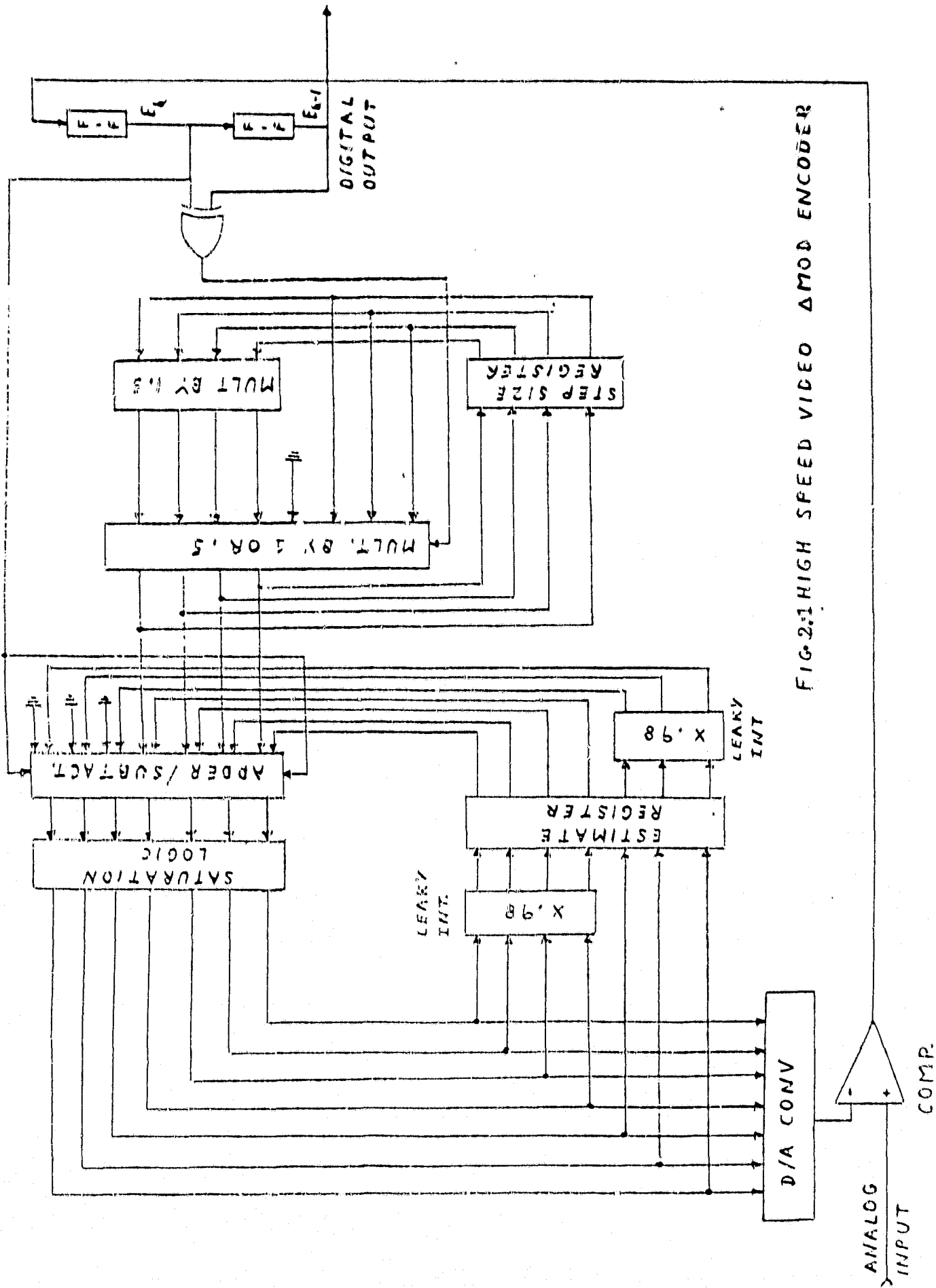
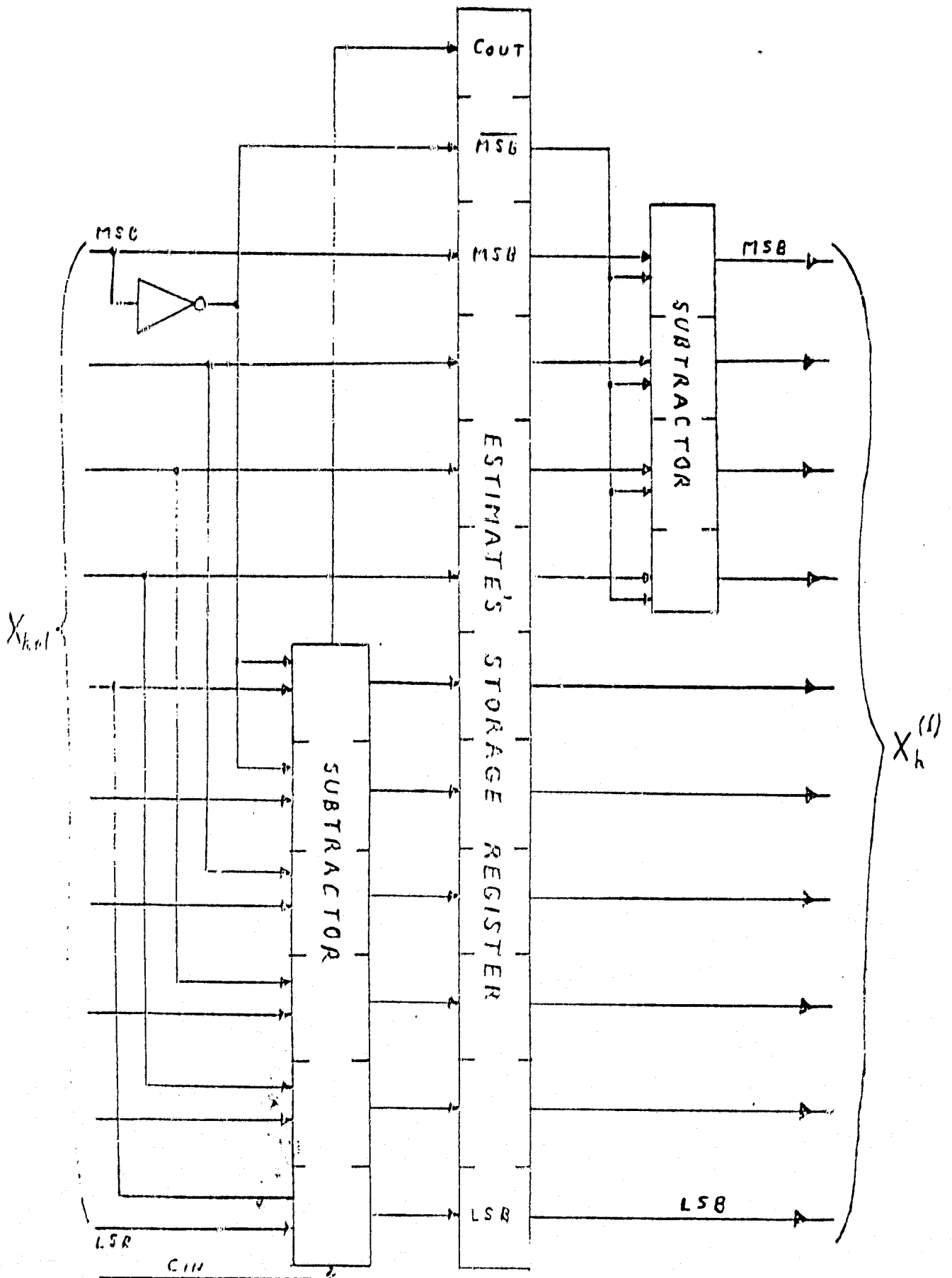


Fig. 2.2 Leakey Integrator



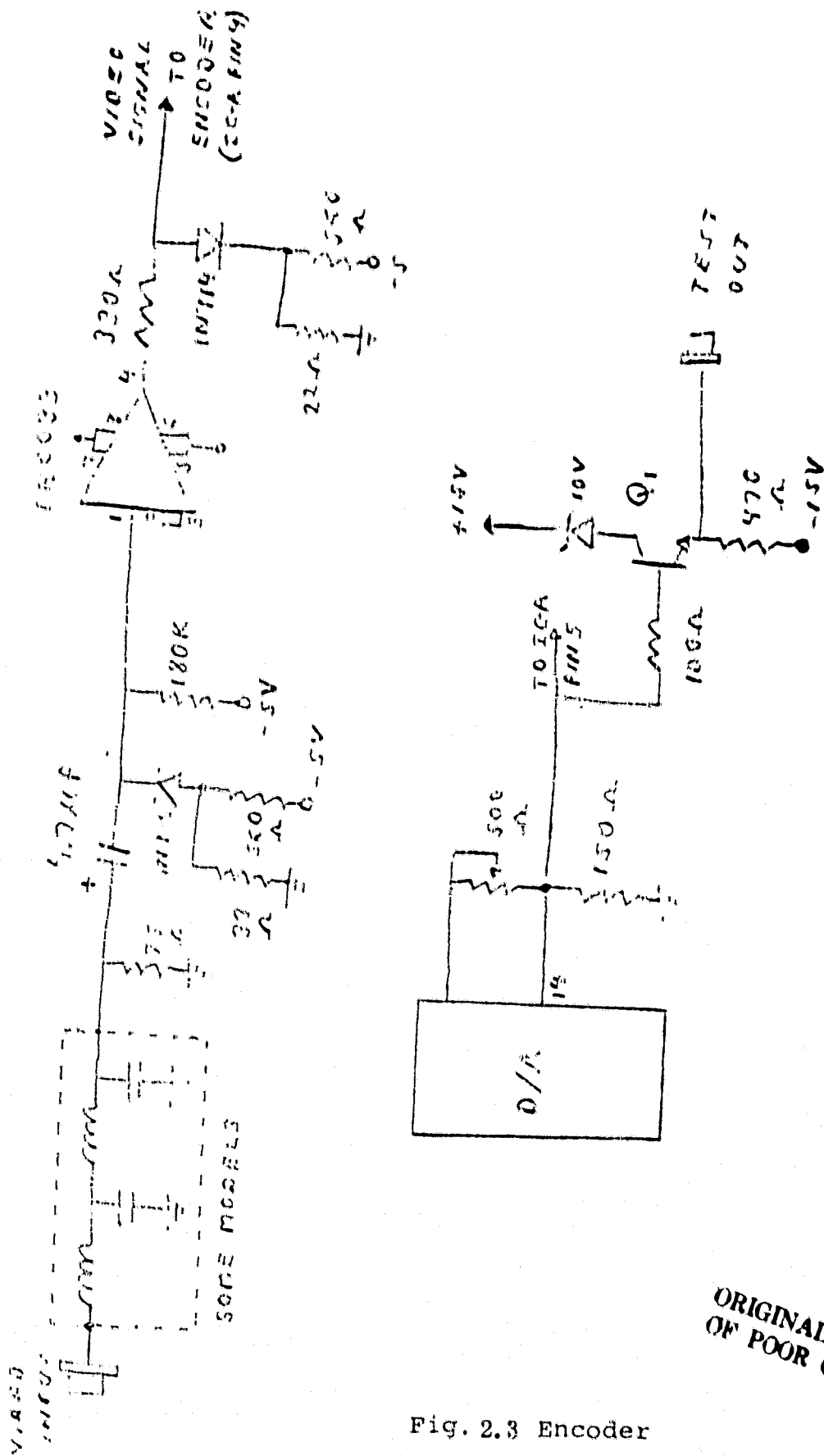
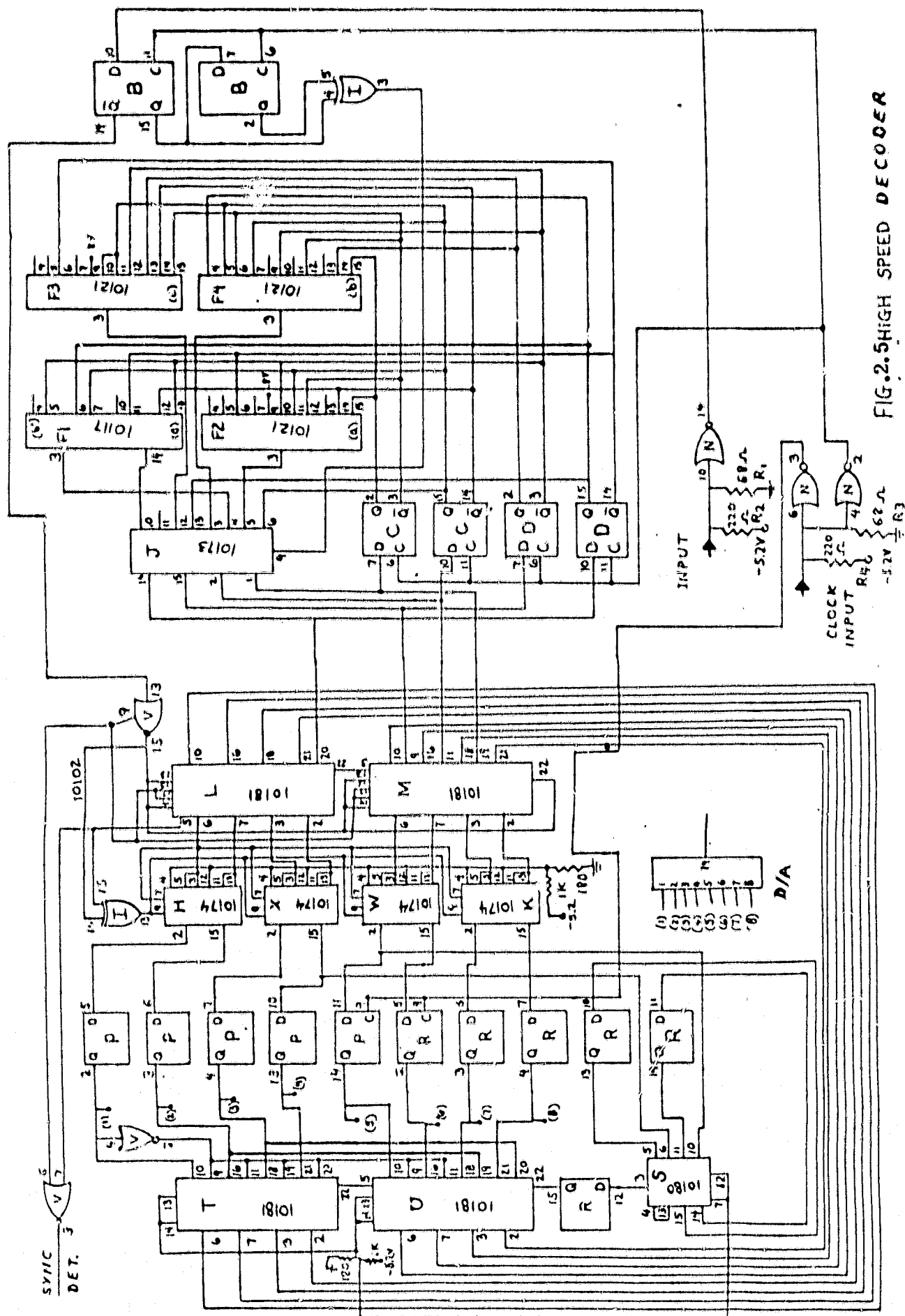


Fig. 2.3 Encoder

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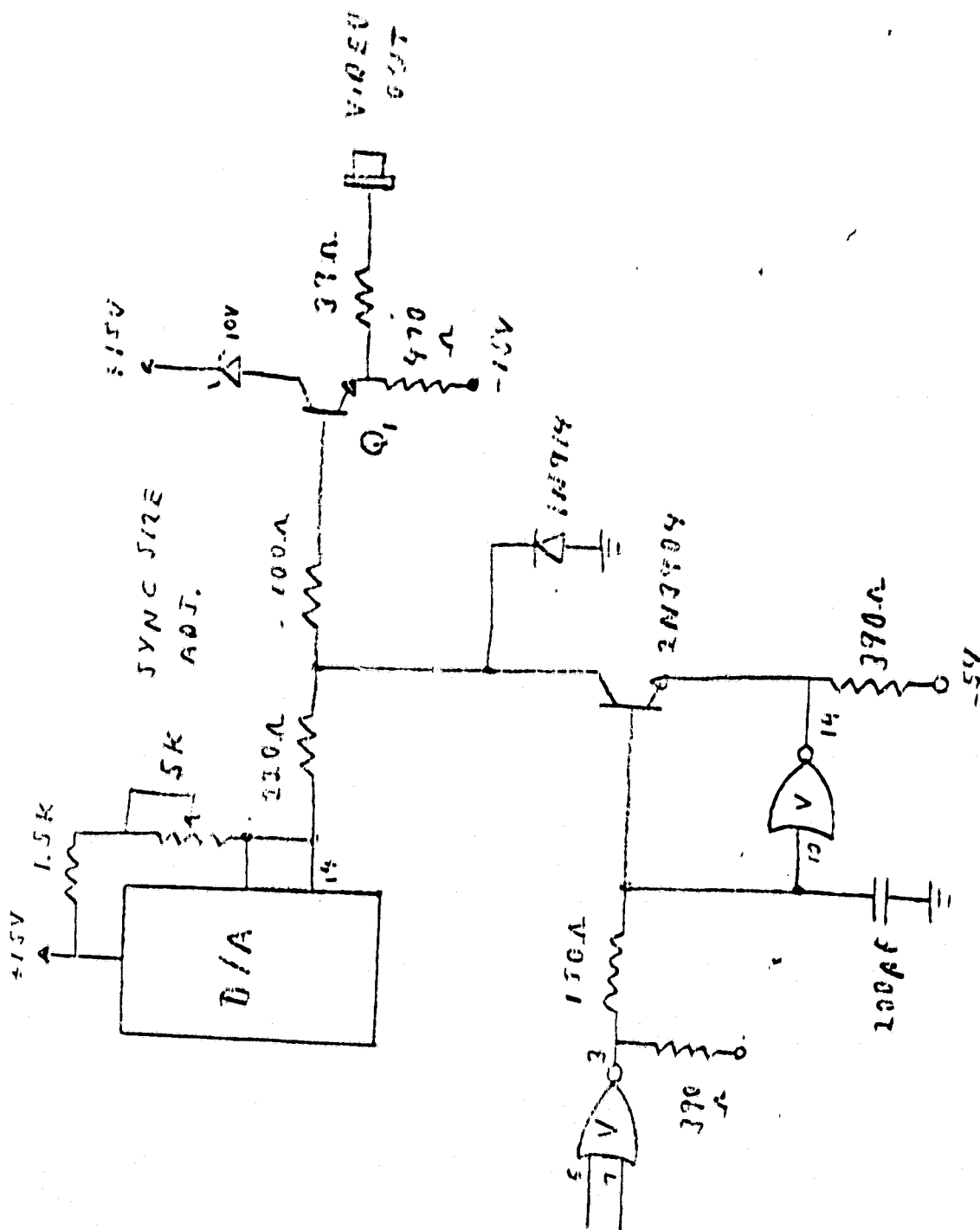


Fig. 2.6 Decoder



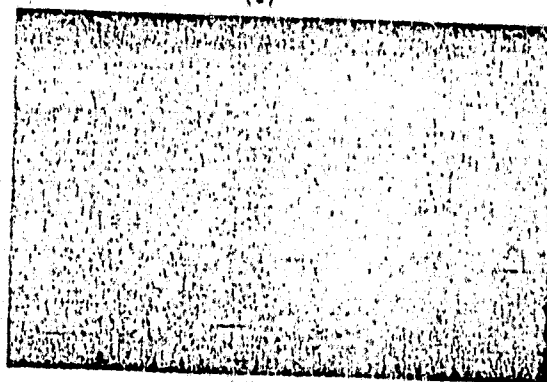
(a)



(b)



(c)



(d)

Fig. 2. 7 Response of ADM to channel errors.

(a) No errors (b) $P_e = 10^{-3}$ (c) $P_e = 10^{-2}$
 (d) $P_e = 10^{-2}$

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DIGITAL ENCODING OF NTSC COLOR VIDEO SIGNALS USING ADAPTIVE DELTA MODULATION

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ABSTRACT

This paper presents the initial results of our study of the use of adaptive delta modulation to encode color signals. The technique considered include direct encoding of the color video signal, encoding of each of the three color components, i.e., R, G and B and, encoding of the chrominance and luminance signals I, Y and Q. It is shown that at any transmitted bit rate between 8Mb/s and 24Mb/s the best quality picture reproduction occurs when the I, Y and Q signals are encoded and the poorest quality picture reproduction occurs when the composite video signal is encoded. Furthermore, the differences in quality are significant.

INTRODUCTION

Every since digital systems were introduced they have met with ever growing acceptance. Their ability to make decisions based on present and past data gives them a high degree of intelligence which, when combined with the high speed operation of digital integrated circuits provides a clear advantage over analog circuits in many areas.

With the advent of ECL and very high speed D/A converters it has become feasible to apply digital techniques to video transmission. In this report we discuss digitally encoding a color video signal using adaptive delta modulation (ADM). Three of the many reasons for employing digital encoding are (1) the encoded signal may be readily and securely encrypted, (2) the digital signal can be transmitted over longer distances and with a higher SNR than an analog signal and (3) when employing ADM the system is relatively immune to channel errors and can operate at bit error rates of 10^{-3} with only small degradation of the picture quality.

NTSC

The standard employed to encode a video picture is the NTSC. In this system anyone having a B/W monitor will receive the picture and display the complete picture as though a B/W picture was transmitted. On the other hand anyone having a color monitor will display the total color picture, by using the chroma information in the decoding process.

A color camera actually records the three principal colors: red (R), green (G) and blue (B). These three colors are then converted into three other signals called I, Y and Q. The signal Y is called the luminance and is the signal detected in a B/W monitor. In terms of the R, G and B signals,

$$Y = 0.3 R + 0.59 G + 0.11 B \quad (1)$$

The three colors R, G and B are also used to form I and Q:

$$I = 0.6 R - 0.28 G - 0.32 B \quad (2)$$

and

$$Q = 0.21 R - 0.52 G + 0.31 B \quad (3)$$

The I and Q signals are also transmitted and it is the detection of the presence of these I and Q signals in the color monitor, in addition to the Y signal, that enables the decoding of the R, G, and B and the displaying of a color picture.

The I and Q signals are quadrature amplitude modulated onto a carrier frequency of 3.57 MHz. Thus, the complete color signal is

$$V(t) = Y(t) + I(t) \cos(\omega_0 t + 33^\circ) + Q(t) \sin(\omega_0 t + 33^\circ) \quad (4)$$

In the color monitor the signal is separated into the luminance and chrominance signals and the R, G and B colors are then extracted using a network which, in essence solves the matrix

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.96 & 1 & 0.62 \\ -0.27 & 1 & -0.65 \\ -1.11 & 1 & 1.7 \end{bmatrix} \cdot \begin{bmatrix} I \\ Y \\ Q \end{bmatrix} \quad (5)$$

The three color signals R, G and B are bandlimited to about 4.0 MHz but the luminance signal has most of its power in the 0 to 3.3MHz band. The inphase signal I is bandlimited to about 1.5 MHz, and the quadrature signal Q is bandlimited to 0.5 MHz.

This bandlimiting of the chroma information has the effect of severely distorting the color content of the small picture elements.

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However, the psychovisual properties of the eye are such that the color content of small objects is irrelevant and therefore the effect of the distortion is small.

Digital Encoding Using PCM

When digitally encoding a color video signal using PCM we sample at about 9 M samples/s and encode using 8 bits/sample. The result is a transmitted bit rate of 72 Mb/s which requires a transmission bandwidth of 72 MHz. If the encoder employed 6 bits/sample, the quantization noise becomes noticeable, however, the required bandwidth is reduced to 54 MHz. In either case the bandwidth is increased considerably over the analog bandwidth needed for the unencoded video signal.

Another difficulty encountered when using PCM is its response to channel errors. For example consider an error rate of 1 error in 100,000 bits ($P_e = 10^{-5}$). This is a low error rate! There are approximately 250,000 picture elements (pels) per frame of signal. If each pel requires 8 bits, then there are 2 M bits received/frame. If 1 in 100,000 bits are received incorrectly, then 20 pels will, on the average, be in error. Furthermore, the size of the error is equally likely to have any possible value. At an error rate of 10^{-4} , 200 pels would be in error. Since each error could be quite large the errors are noticeable and the picture is unpleasant to view when the error rate approaches 10^{-4} .

1. Digital Encoding Using ADM

When we encode a color video signal using adaptive delta modulation (ADM) the bandwidth required is one-half that employed for PCM to obtain a comparable quality picture. In addition, most of the time, when an error occurs it will be small, i.e., the probability of the amplitude of the error appears somewhat gaussian as contrasted to the uniform density of the error amplitude found in PCM. Thus, the ADM can operate at error rates exceeding 1 error/1000 bits while PCM is limited to about 1 error/100,000 bits.

It was the combination of low bit rate and relative immunity to channel errors which caused us to investigate ADM techniques of encoding color video signals.

2. The SONG ADM Algorithm

The algorithm used for ADM encoding a color signal is the same as for a B/W signal and is repeated below for completeness:

$$E_{k+1} = \text{sgn}(S_{k+1} - X_{k+1}) \quad (6)$$

where S_{k+1} is the input signal sampled at time $t = (k+1)T_s$, X_{k+1} is the estimate and E_{k+1} is sign of the bit transmitted to the receiver at time $(k+1)T_s$. The estimate X_{k+1} is given by the equation

$$X_{k+1} = X_k + Y_{k+1} \quad (7)$$

where Y_{k+1} is the "step-size" at $t = (k+1)T_s$:

$$Y_{k+1} = \begin{cases} |Y_k| \begin{cases} E_k + 0.5 E_{k-1} \\ \leq Y_{\min}/1.5, E_k = E_{k-1} \\ < Y_{\max}, E_k \neq E_{k-1} \\ \geq 2 Y_{\min} \end{cases} \\ 2 Y_{\min} E_k & ; |Y_k| < 2 Y_{\min} \\ Y_{\max} & ; |Y_k| > Y_{\max}/1.5, E_k = E_{k-1} \end{cases} \quad (8)$$

In Eq. 8 Y_{\min} and Y_{\max} represent the minimum and maximum step size values, respectively, and were chosen to be (see Ref. 1 P 40):

$$Y_{\min} = 2^{-6} \cdot S_{\max} \quad (9a)$$

and

$$Y_{\max} = 2^{-2} \cdot S_{\max} \quad (9b)$$

where S_{\max} is the maximum peak-to-peak signal amplitude.

3. ADM Encoding of the Composite Signal

Our previous report ⁽¹⁾ indicated that B/W video pictures can be encoded using bit rates from 8-16 Mb/s. At 8 Mb/s the picture quality was rather poor showing significant edge busyness. At 16 Mb/s the edge busyness was reduced to the size of about 1 pel and so the picture quality was quite good. A graph of subjective evaluation of the picture quality vs. sampling rate is shown in Fig. 2. It is seen that a rapid improvement in picture quality is obtained when going from 8 to 16 Mbps. Above 22 Mbps the picture quality improves very slowly.

The reason is that the quantization noise in each sample is proportional to the clock rate (i.e. it approximately halves when doubling the clock rate). When the quantization noise is large (at say 8 Mbps) we obtain a very noticeable improvement by halving it (using a clock rate of 16 Mbps). However, beyond 16 Mbps, the noise is small and we no longer get drastic improvement by increasing the clock rate.

When we attempted to encode the composite color signal, the increased bandwidth, required an increased bit rate. Even at a sampling rate of 24 Mb/s the quality of the color signal was not good and the red colors appeared "washed-out" as shown in Fig. 3⁽²⁾. Higher bit rates than 24 Mb/s were not employed since our ECL constructed system could not process the data at a higher bit rate than this.

(1) "Effect of Interference on Delta Modulation Encoded Video Signals" Semi-Annual Report, Oct. 1 1978 - April 1, 1978, NASA/GODDARD

(2) "Voice Encoding for the Space Shuttle Using ADM" IEEE 11/78.

4. Encoding the R, G and B Signals

The first technique attempted, to provide faithful color reproduction was to encode each of the colors R, G and B separately. This requires the use of 3 delta modulator encoders and 3 decoders as well as a multiplexing and demultiplexing circuit. Since each color utilizes the full 3.3 MHz bandwidth one would expect that each ADM should be operated at 16 Mb/s to obtain good quality color. The transmitted bit rate in this case would be 48 Mb/s.

Indeed, at 48 Mb/s the color quality is very good, however, for many applications, such as teleconferencing, each ADM can be operated at 8 Mb/s. When this sampling rate is used the color quality is far better than that obtained when encoding the composite picture. However, the edge busyness is greater. Fortunately, the edge busyness is not as significant as found when encoding B/W at 8 Mb/s. The reason for this is that the edge busyness for each color is different and the combined picture has a smeared edge similar to what is obtained using dithering. Figure 4 shows the complete color picture which requires a 24 Mb/s rate. Figure 5 shows the complete picture at 48 Mb/s. Note the significant improvement in picture quality.

5. Encoding the I, Y and Q Signals

To encode the I, Y and Q signals, the three camera outputs R, G and B are passed through a weighting matrix having the characteristics of Eqs. 1, 2 and 3. The Y signal representing the luminance (or B/W signal) is encoded at 16 Mb/s, however the I and Q signals have a significantly smaller bandwidth and were encoded at 4 Mb/s each. The resulting transmitted bit rate is then $16 + 4 + 4 = 24$ Mb/s. Recovery in the receiver is accomplished by demultiplexing, ADM decoding the I, Y and Q signals, and then passing these signals through the decoder matrix given by Eq. 5.

The quality of the color reproduction was excellent as long as the I and Q channels operated at 4 Mb/s. When the bit rate was reduced the color picture quality degraded rapidly. As the bit rate used to encode Y decreased the quality decreased slowly and the edge busyness increased. The decrease in picture quality follows the curve of B/W picture quality vs. sampling rate as shown in Fig. 2.

Figure 6 shows the color picture when encoded at 24 Mb/s using I, Y and Q encoding. Note that the quality is superior to that shown in Fig. 3 which employed R, G and B encoding.

6. Line Sequential Encoding

A "line sequential" encoding system is shown in Fig. 7. We see that there are 3 encoders, one for each color R, G and B. To illustrate the system operation assume we are to encode the odd field of lines 1, 3, 5, 7, etc. Then encoder "R" encodes

line 1, encoder "G" encodes line 3 and encoder "B" encodes line 5. This procedure continues with encoder "R" encoding lines $6n+1$, encoder "G" encoding $6n+3$ and encoder "B" encoding lines $6n+5$.

In the receiver, when line $6n+k$ ($k = 1, 3$ or 5) is to be viewed, we present to the monitor the outputs of the three ADM decoders for lines $6n+k-4$, $6n-k-2$ and $6n+k$.

As a result of encoding a single color for each line, we are capable of reproducing a fairly good quality color signal using only 16 Mb/s. The drawback to this system is that we encode every other line not adjacent lines. Thus, some "flickering" results when two areas of contrasting colors are adjacent vertically. A second effect of this vertical "averaging" is that we tend to ease small curvatures such as lips, eyes, etc. Also, small curves such as flowers, elbows, etc. develop a staircase pattern which tends to be very annoying.

However, for low bit rate encoding this system appears to provide the best quality of the above techniques. Figure 8 shows the result of encoding a color picture, using line sequential encoding, at 8 Mb/s and at 16 Mb/s.

Conclusions

It is difficult to compare the RGB, IYQ and line sequential systems since their drawbacks and advantages are quite different. For high available bandwidth, where good color and high quality detail reproduction is desired, one should use the RGB system.

When good color quality is desired together with the ability to have a trade-off between quality and available bandwidth when the quality varies from poor to almost broadcast quality and the transmission rate from 16 to 30 Mbps, we believe that the IYQ system is best.

It can achieve a quality comparable to that of the RGB system but at lower bit rates. The degradation obtained from this system is apparent in the color reproduction of the small picture elements.

For very low available bandwidth the only choice is the line sequential system. Here the main difficulty lies with the vertical smearing which could cause small vertical detail to be altogether lost. This distortion is indicative of the low clock rate.

We conclude that the above research has achieved its aims:

All of the above methods achieve "good" picture quality. As the bandwidth becomes more limited, the degradation becomes more severe. However, the degradation is far less severe than when using PCM. This degradation does not happen to the color quality

but to the luminance information. Furthermore, the three methods are not overlapping, but should be used depending on the available bandwidth and accuracy required.

The systems have not yet been tested in the presence of channel errors. However, based upon our previous experience we expect the systems to be robust to such noise.

Acknowledgement

We wish to thank Dr. D. Kahle of Goddard Space Flight Center for his many helpful suggestions.

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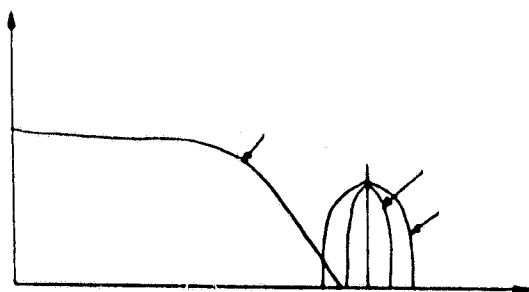


Fig. 1 Spectrum of NTSC Video Signal

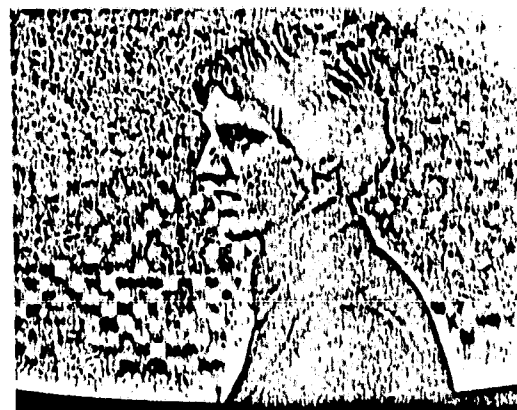


Fig. 3 NTSC Video Signal Encoded at 1.6 Mb/s

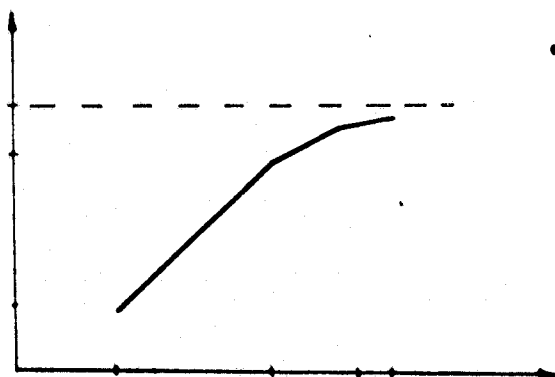


Fig. 2 Subjective Picture Quality vs. Bit Rate.



Fig. 4 RGB Encoding at 24 Mb/s (8 Mbs per channel)



Fig. 5 RGB Encoding at 48 Mb/s (16 Mb/s per channel)



Fig. 8a Line Sequential System at 8 Mb/s



Fig. 6 IYQ Encoding at 24 Mb/s (16 Mb/s for Y, 4 Mb/s for Q and I)



Fig. 8B Line Sequential System at 16 Mb/s

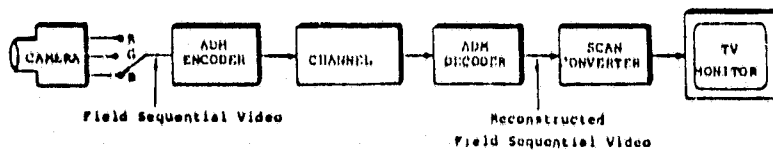


Fig. 7 Line Sequential System

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